

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

April 1942 as

Advance ~~Restricted~~ Report

FLIGHT INVESTIGATION OF THE PERFORMANCE AND

COOLING CHARACTERISTICS OF A LONG-NOSE

HIGH-INLET-VELOCITY COWLING ON THE XP-42 AIRPLANE

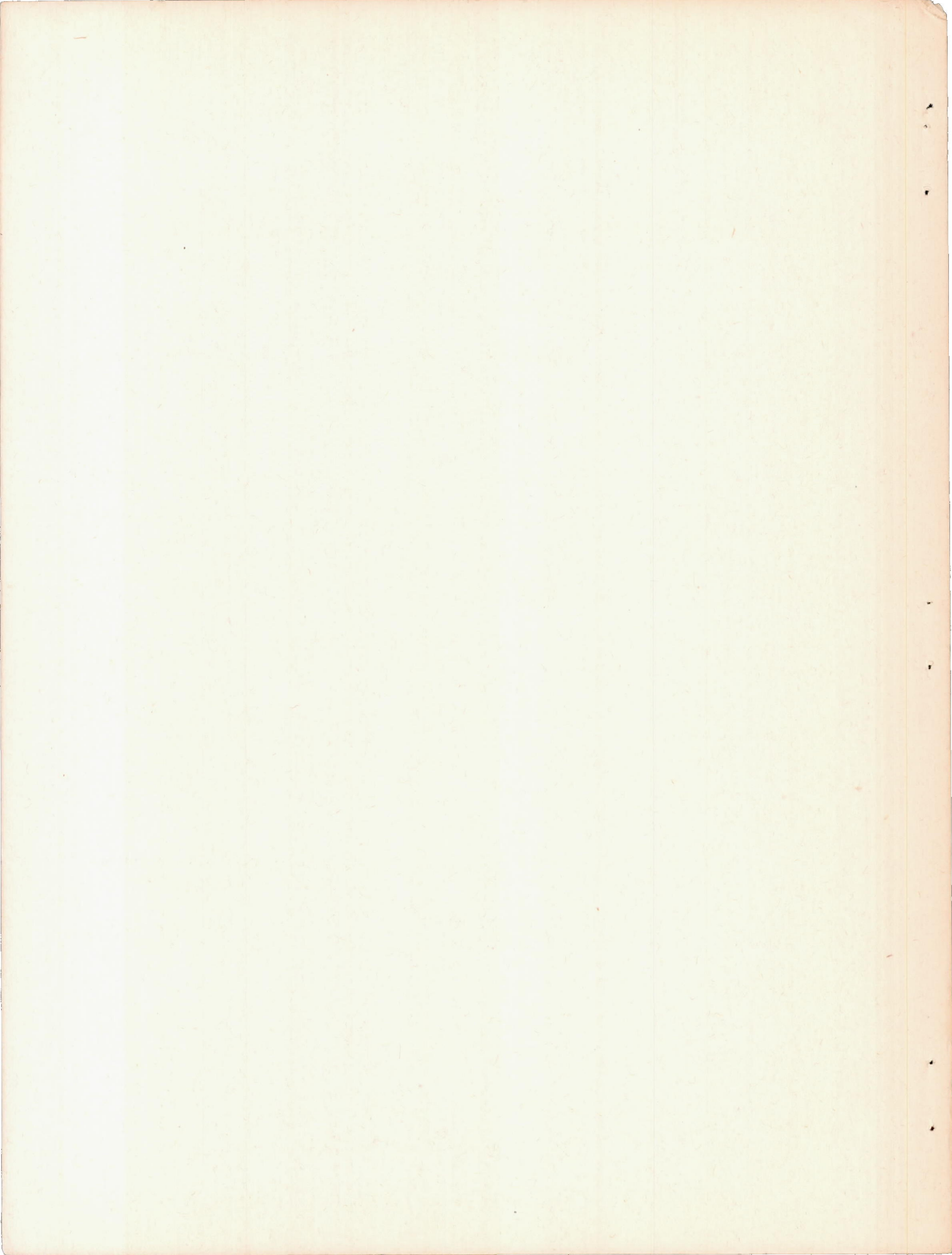
By F. J. Bailey, Jr., J. Ford Johnston, and T. J. Voglewede

Langley Memorial Aeronautical Laboratory
Langley Field, Va.



WASHINGTON

NACA WARTIME REPORTS are reprints of papers originally issued to provide rapid distribution of advance research results to an authorized group requiring them for the war effort. They were previously held under a security status but are now unclassified. Some of these reports were not technically edited. All have been reproduced without change in order to expedite general distribution.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE ~~SECRET~~ REPORT

FLIGHT INVESTIGATION OF THE PERFORMANCE AND

COOLING CHARACTERISTICS OF A LONG-NOSE

HIGH-INLET-VELOCITY COWLING ON THE XP-42 AIRPLANE

By F. J. Bailey, Jr., J. Ford Johnston, and T. J. Voglewede

SUMMARY

The results are presented for a series of flight tests of the maximum speed and the cooling characteristics in high-speed level flight and in climb of the XP-42 airplane equipped with a long-nose high-inlet-velocity cowl. This cowl is the first of a series being tested in an effort to improve the performance and cooling characteristics of air-cooled engine installations.

The results of the tests indicated a maximum speed of 338 miles per hour at 870 horsepower at 17,000 feet, which was above the engine critical altitude.

Pressure measurements in the entrances to the cylinder baffles showed a uniform distribution of pressure on the front of the engine in high-speed level flight and a fairly uniform distribution in full-power climb. Static pressure behind the engine was uniform in level flight but high at the bottom of the engine in climb.

In high-speed level flight, front pressures on the engine averaged 83 percent and rear pressures averaged 43 percent of free-stream impact pressure. The resulting pressure drop of 14 inches of water at 16,000 feet adequately cooled the cylinder heads; maximum cylinder base temperatures, however, exceeded the specified limit when corrected to Army summer conditions.

In full-power climb at an indicated speed of 140 miles per hour, front pressures on the engine averaged 86 percent and rear pressures 26 percent of free-stream impact pressure but decreased as the power fell off at high altitude. The resulting pressure drop of approximately 10½ inches of water was sufficient to keep cylinder temperatures within their specified limits when the carburetor setting was full rich.

It is pointed out that the value, for cooling, of any

type of cowlings should be judged on the basis of the amount and the distribution of the cooling-air pressures it can supply to the engine and not on the basis of temperatures observed for any one particular engine.

INTRODUCTION

In an extensive series of flight tests with the Curtiss XP-42 airplane, the NACA is investigating the characteristics of several different cowlings designs proposed for radial air-cooled engines. When originated, this program had two principal objectives: first, to determine the maximum speed of the airplane with its original long-nose engine when fitted with what appeared, on the basis of wind-tunnel investigations, to be an optimum air-cooled engine installation; and second, to establish the extent to which maximum speed would suffer as attempts were made to adapt the optimum arrangement to the standard short-nose engine in order to produce more practicable designs from the considerations of weight and ease of fabrication.

It was recognized that the high-speed values for any particular arrangement would have little significance unless accompanied by data showing the arrangement to be capable of providing satisfactory engine cooling in all flight conditions. Accordingly, the tests were planned to include measurement of the cooling capabilities of each arrangement in a number of the more critical conditions. Subsequent increases in the number of arrangements to be tested, however, have made it necessary to confine investigation of the cooling characteristics to two flight conditions: high-speed level flight at critical altitude with military power, and sustained climb to approximately 20,000 feet with military power, at airspeeds in the neighborhood of that for best rate of climb. Ground-cooling characteristics are being investigated prior to the flight tests of each arrangement.

The cowlings designs to be tested are an outgrowth of recent wind-tunnel investigations reported in reference 1. In general, they represent an effort to improve the external cowl shape with reference to drag and critical speed and to maintain a high, uniformly distributed cooling-air pressure over the front of the engine in both climb and level flight. At present, the program includes tests of the type D_L long-nose high-inlet-velocity cowlings reported herein and designed for the long-nose Pratt &

L-356
Whitney 1830-31 engine, a D_S short-nose high-inlet-velocity cowling designed for the standard short-nose Pratt & Whitney 1830 engine; a D_{ST} short-nose low-inlet-velocity cowling designed for use with a spinner-mounted axial-flow fan; and a conventional NACA C type cowling.

The use of propeller cuffs is considered mandatory with both high-inlet-velocity designs if only on the basis of ground cooling. During tests of the low-inlet-velocity cowling, however, the several modifications that can be achieved by removing the cuffs, the fan, or both will probably be tried. Wherever possible, when cuffs are used, two angular settings will be tried in an effort to obtain the optimum cuff setting.

Although a conclusive analysis of the relative merits of all the different arrangements cannot be made until the entire program is complete, test data on each arrangement will be reported briefly as soon as obtained. The present paper may be considered the first of this series of reports. It includes the data obtained in tests of the long-nose high-inlet-velocity cowling, which was the first to be tested.

The design of the cowling and engine installation was a project of the Air-Cooled Engine Installation Group stationed at the Laboratory. The portion of this group associated with this project included Mr. Howard S. Ditsch, of the Curtiss Company; Mr. Peter Torracco, of the Republic Company; Mr. William S. Richards, of the Wright Company; and Mr. James R. Thompson, of the Pratt & Whitney Company. The Matériel Division of the Army Air Corps sponsored the investigation and supplied the XP-42 airplane. The Airplane Division of the Curtiss-Wright Corporation handled the construction as well as the structural and detail design of the cowling and supplied personnel to assist in the servicing and maintenance of the airplane and cowling during the tests. The Pratt & Whitney Company prepared the engine and torque meter for the tests and assisted in the operation and servicing of the engine. The propeller, cuffs, and spinner were supplied by the Propeller Division of the Curtiss-Wright Corporation.

RELATION OF COWLING TO ENGINE COOLING

Any attempt to analyze the test data in this paper and

in subsequent reports of this series to ascertain whether a given cowling arrangement is capable of fulfilling its duties in cooling the engine must start with a definition of those duties.

Briefly, the responsibility for cooling the engine can be divided between the cowling, the lubricating system, the cylinder fin and baffling arrangement, and the induction system. It is the duty of the cowling to convey to the front of the engine a suitable quantity of air at a high pressure, uniformly distributed over the entrances to the cylinder baffles. Over the rear of the engine the cowling must provide a uniformly distributed pressure controllable over a range sufficient to maintain an approximately constant difference between front and rear pressures as the airplane speed is varied from the maximum in level flight to that for best rate of climb.

It is also the duty of the cowling to contribute to the internal cooling of the cylinders by providing for efficient operation of the oil cooler. The lubricating system is of course charged with distributing the cooled oil uniformly to the cylinders.

It is the duty of the fin and baffle combination to so distribute the air over the cylinders that heat is removed from each region on the cylinder surface at the rate necessary to maintain the temperature of that region at the highest value compatible with satisfactory engine life.

It is the duty of the engine induction system to distribute uniformly to the different cylinders the minimum excess of gasoline that experience has indicated to be necessary for internal cooling of the cylinders.

On the basis of the foregoing considerations it is evident that the conventional method of evaluating engine cooling by measurement of index temperatures on the cylinders gives only the total effect of all the factors that contribute to engine cooling and is therefore a particularly inconvenient, if not wholly unreliable, index of the merit of the cowling. It is also apparent that any inequality in the division of oil, gasoline, or cooling air between the individual cylinders, as well as any deficiency in the distribution of fin area or cooling air over the different parts of each cylinder, correspondingly increases the demand on and reduces the efficiency of the cowling, which must be made capable of supplying a pressure drop

over the entire engine sufficient to eliminate the worst existing case of local overheating. Obviously when such localized overheating is severe, no cowling can be expected to produce satisfactory cooling.

Although a complete survey of engine temperatures was planned, and still is being included in all the tests in the present series, it now appears obvious that the very extensive survey also being made of pressures at the entrances to the baffles of the different cylinders and in the compartment behind the engine is a much more direct and reliable measure of the cooling capabilities of the different cowlings.

XP-42 AIRPLANE WITH LONG-NOSE COWLING

The XP-42 airplane shown in figures 1, 2, and 3 is identical with the P-36 airplane except in the fuselage fairing behind the cowling and in the engine installation. Its engine, the Pratt & Whitney 1830-31, has a higher critical-altitude rating and incorporates an extension shaft that places the propeller approximately 20 inches ahead of the normal position. The power rating of the engine is as follows:

	bhp	rpm	Altitude, feet
Take-off	1050	2550	0
Normal rating	1000	2300	8,500
Normal rating	1000	2450	11,500
Military rating	1000	2700	14,500

The engine has a single-stage blower with an impeller drive ratio of 8.47 : 1 and a propeller drive ratio of 16:9. A special set of engine-cylinder baffles, designed to minimize the leakage of air between adjoining baffles and to fit more closely to the fins, was provided by the engine manufacturer.

The 10-inch-diameter oil cooler furnished with the engine was believed to be marginal and was replaced by an 11-inch U.A.P. cooler with the same core depth of 9 inches.

Individual cylinder jet exhaust stacks, reference 2, were used in place of the standard collector ring. These stacks, figure 4, are made of $2\frac{5}{8}$ -inch-outside-diameter by 0.049-inch-wall stainless-steel tubing. The ends of the stacks are flattened to reduce the internal cross-sectional area from 4.05 to 2.98 square inches.

A dimensioned drawing of the cowling and propeller cuffs is shown in figure 5. It will be noted that all cooling and induction air is taken in through a single opening at the nose of the cowling. The division of the air is made in the low-velocity region at the end of the diffuser. Figure 6 is a close-up view of the cowling and cuffs.

As tested in the high-speed condition, there were two small cowl flaps on each side of the engine. Since these flaps were found inadequate for cooling in a full-power climb, three fixed cowl flaps were added to each side for the climb tests. They may be seen as installed in figures 7 and 8.

Fuselage side panels, as reported in reference 1, were used to improve the fairing of the cowling into the fuselage. The airplane, as prepared for the tests, weighed 6000 pounds with a 175-pound pilot and full tanks. It retained the standard aerial but had no provisions for guns.

TEST APPARATUS

The pressure and the velocity of the air entering the engine compartment from the rear of the diffuser section were measured by four survey rakes disposed symmetrically at the top, bottom, and both sides of the annular opening. Each rake consisted of five impact tubes spaced radially from the inner to the outer edge of the opening and a static tube offset laterally about 1 inch from the center impact tube.

The pressure drop across the engine was measured by impact tubes set in the entrance to the baffles on top of the head; by impact tubes on the exhaust side of the head; by impact tubes on the exhaust side of the barrel of cylinders 1, 3, 4, 6, 7, 9, 10, 12, and 14; and by open-end tubes shielded from direct air flow behind each of the cylinders listed.

L-356

The ram in the carburetor scoop was measured by three impact tubes on the vertical center line of the scoop and slightly behind the center line of the rear cylinders. In addition, for the earlier flights, seven impact tubes were placed at the entrance to the carburetor, just above the screen, to determine the pressure distribution at the carburetor. Figure 9 shows the relative locations of pressure tubes in the cowl.

Nine impact tubes and one static tube were placed in the face of the oil cooler to determine the ram at that point; three impact tubes facing into the exit cooling air stream about $3/4$ inch behind and on the vertical center line of the oil cooler were used in determining the pressure behind the oil cooler.

After the preliminary flights, open-end tubes were also put in the accessory and recording instrument compartments to determine the pressure at those points.

The 85 air pressures were recorded by a 30-cell recording manometer attached to the pressure tubes through a manually operated three-position switch (fig. 10) so that each cell recorded the pressures from three different tubes in succession. The static sides of all cells were attached to a common pressure source, and the pressure side of one cell recorded free-stream total pressure; thus all pressures could be measured in inches of water above or below free-stream total pressure.

Principal temperature measurements were made by means of iron-constantan thermocouples connected to a recording galvanometer through a motor-driven 48-position rotating switch (fig. 11). With this arrangement, each temperature was recorded approximately once every 90 seconds.

For the measurement of cylinder-head temperatures, a gasket-type thermocouple was used under the rear spark plug of each cylinder. Cylinder-barrel temperatures were measured by thermocouples peened into the flanges at the rear center lines.

Thermocouples were also placed on the front and rear spark-plug elbows of cylinders 1, 7, and 11; on both magnetos; on the fuel lines on the suction and pressure sides of the fuel pump; in the primer holes in the intake ports of cylinders 5 and 10 for intake mixture-temperature; in the mixture at the supercharger blower rim; and in the oil-

out line. The cooling-air temperature was recorded by a thermocouple at the annular entrance to the engine compartment and by thermocouples ahead of and behind cylinder 1. The thermocouple behind cylinder 1 was placed 2 inches behind and three fin spaces above the bottom of the head; the front thermocouple was between cylinders 2 and 14 and about three fin spaces below the bottom of the head. The carburetor-air temperature was recorded by a thermocouple just under the screen at the carburetor entrance.

The cold junctions of the thermocouples were taped in a bundle about 3 feet long and 3 inches in diameter and placed in the rear part of the fuselage. A resistance bulb thermometer was used to indicate the temperature at a point in the bundle. Indicated temperatures were noted by the pilot. Other temperatures indicated by resistance bulb thermometers were the temperatures of the accessory-compartment air and the air at exit from the oil cooler. Free-air, oil-in, and carburetor-mixture temperatures were measured by Army standard vapor-pressure type instruments already in the airplane. The free-air thermometer was calibrated for the compressibility heating effect due to speed by flying at constant altitude at several airspeeds.

An oil-pressure-type torque meter was installed in the nose of the engine, with a 400-pound gage in the cockpit. The pilot's readings of the torque-meter gage and tachometer were used in determining the brake horsepower delivered to the propeller.

Altitude was determined by a recording altimeter open to the measured pressure of the instrument compartment behind the pilot's seat. Airspeed was determined by an airspeed recorder working on pressures from an NACA swiveling airspeed head on the right wing tip about one chord length ahead of the leading edge of the wing. The static side of the airspeed head was calibrated by attaching it to a calibrated sensitive altimeter and flying at several airspeeds at a known low geometric height, for which true barometric pressure could be accurately established. The impact side was calibrated against a shielded pitot head free from errors due to flight angles of attack. A cross-calibration between the service airspeed head on the left wing and the NACA airspeed head was later obtained, and the NACA head was removed for the last high-speed trials.

Attempts were made to measure the fuel flow to the

carburetor by means both of an NACA indicating flowmeter and a Bowser type flowmeter. Results obtained by either method of measurement were inconsistent within themselves and were discarded as being unreliable.

TEST PROCEDURE

Before the flight tests, ground-cooling tests were made by running the engine at 1380 rpm in low pitch for 10 minutes, then idling for 5 minutes; then, after about a minute of running at higher speed to clear the spark plugs, cutting off the engine. Temperatures were recorded continuously until about 10 minutes after the engine was stopped. The small cowl flaps were open.

Preliminary flights were then made to calibrate the airspeed head and free-air thermometer and to check the engine cooling at full power at critical altitude.

After several changes indicated by the results of the preliminary flights, the high speed was determined by making level runs at full power at 2700 rpm with cowl flaps closed at several altitudes at and above the engine critical altitude. The manifold pressure was not allowed to exceed 39 inches of mercury during the high-speed runs. After reaching steady conditions in each run, the pilot switched on the manometer and took pressure records, meanwhile noting free-air and cold-junction temperatures, torque and manifold pressure, and engine speed. All recording instruments, except the manometer, were left on throughout the flight.

For tests of the cooling in climb, the general procedure was to hold the airplane at a constant propeller speed and indicated airspeed and at predetermined manifold pressures or at full throttle. Of the climb tests reported here, one was made at 160 miles per hour at 2550 rpm and about 40.5 inches of mercury in the automatic rich carburetor setting and was repeated at 2300 rpm; the other was at 140 miles per hour and 2550 rpm with the mixture control in full rich. In the full-rich climb the manifold pressure was held at 44.5 inches of mercury to 7000 feet, then 43.5 inches of mercury until the full-throttle position was reached. All climb tests were made with the full cowl flaps fixed open.

The change in mixture setting from automatic to full rich was made when tests showed that the engine could not be satisfactorily cooled in automatic-rich setting at climbing speeds below 160 miles per hour; whereas, the best climbing speed was expected to be approximately 140 miles per hour. The automatic-rich setting provides a mixture compensation for altitude that is cut out in the full-rich setting.

RESULTS AND DISCUSSION

Maximum speed.- The values of maximum speed calculated from data obtained in level runs near and above the engine critical altitude are shown in figure 12, along with the observed brake horsepower and two parameters to be explained later. The power curve shows that the critical engine altitude was not reached, at least in the run at the lowest altitude shown, and that therefore the speed obtained in that run must be expected to be lower than speeds obtained at full throttle at critical altitude.

With the limited number of runs made, the precision of the individual high-speed measurements was insufficient to determine critically the small variation of air-speed with altitude at full throttle in the range of altitudes shown, and the faired curve presented must be considered an approximation. In this connection, it should be noted that an error of approximately one mile per hour in any individual speed determination may result from:

An error of 3° F in free-air temperature

An error of 0.2 inch H₂O in impact pressure

An error of 0.1 inch of mercury in atmospheric pressure

A change of altitude of 40 feet per minute

Of the above sources of error, that in determining the free-air temperature may have been the most important. After the tests were completed, it was found that external pressure has an unexpectedly large effect on the indications of the free-air thermometer. Although all readings have been corrected for this effect, its magnitude,

7° F at 15,000 feet, leaves some doubt as to the general reliability of the instrument. The compressibility effect on the thermometer averaged 15° F at 335 miles per hour, but a series of determinations indicated that this effect may have varied considerably under different atmospheric conditions.

The relation between the observed variations of power and speed with altitude, shown in figure 12, may be more readily analyzed by consideration of the equilibrium of power required and power available in steady level flight.

Under these conditions

$$\frac{DV}{375} = \eta \text{ bhp} \quad (1)$$

or

$$V = 52.73 \left(\frac{\eta}{SC_D} \right)^{1/3} \left(\frac{\text{bhp}}{\sigma} \right)^{1/3} \quad (2)$$

where

D over-all drag of airplane, pounds

V true speed, miles per hour

η propulsive efficiency of propeller and exhaust-stack combination

bhp brake horsepower

S wing area, square feet

C_D drag coefficient of airplane

σ free-air-density ratio

It is immediately apparent that, for full-throttle level flight at and slightly above the critical altitude with an airplane of normal aspect ratio and wing loading and a propeller chosen for good high-speed performance,

the parameter $52.73 \left(\frac{\eta}{SC_D} \right)^{1/3}$ should be virtually unaffected by moderate changes in weight or altitude. Values

of this parameter deduced from the observed values of V and $\frac{bhp}{\sigma}$ for each run are plotted against density altitude in figure 12. The variation of approximately 2 percent in the calculated values is more than would normally be expected in the small range of altitudes tested, and some of the variation should be charged to experimental error in the small number of points obtained.

In full throttle operation the parameter $\left(\frac{bhp}{\sigma}\right)^{1/3}$ would also be expected to remain essentially constant over the altitude range covered by the tests. The measured values of this parameter, which are also plotted against density altitude in figure 12, confirm this expectation.

An important phase of the present investigation involves comparison of the high-speed performance of the long-nose cowl and exhaust-stack arrangement with accepted high-speed performance values for similar airplanes with conventional air-cooled (P-36A) and liquid-cooled (P-40C) installations. To provide such a comparison, equation (2) in the modified form

$$\left(\frac{V}{52.73}\right)^3 = \frac{\eta}{SC_D} \frac{bhp}{\sigma} \quad (5)$$

has been presented graphically on figure 13. Points representing the high-speed performance of the various airplanes, all of which had the same wing area, are spotted on this figure. The location of a point on the figure immediately reveals not only the maximum speed of the airplane but also the manner by which it was attained; by power, supercharging and ram, as indicated by the ordinate scale, or by aerodynamic refinement, as indicated by the abscissa scale.

Within reasonable limits, the figure may be used for several purposes. Primarily, it provides a ready method of determining the effect on maximum speed of changing either the power or the critical altitude of an engine installation. For moderate changes the effect on weight and propulsive efficiency will usually have a negligible effect on the factor $\frac{\eta}{SC_D}$, so that the abscissa of a

point on the figure may be assumed constant while the ordinate is shifted. For example, it would be of interest to determine what would have been the maximum speed of the long-nose XP-42 if its engine had delivered its rated military brake horsepower. For 1000 horsepower at 14,500 feet, the value of the parameter $\frac{bhp}{\sigma}$ would be 1562. With a representative value of $\frac{\eta}{SC_D}$ of 0.1775, the maximum speed would then be expected to be 344 miles per hour, as compared with the observed maximum value of 338 miles per hour. Actually, the ram to the carburetor would permit attaining this power at a lower free-air density and would permit a further increase in speed of approximately 3 miles per hour.

Another use of the chart is for comparison of the maximum speed at the same power and altitude of airplanes of the same wing area, when these airplanes have been tested under different power-density conditions. A necessary pre-supposition to this comparison is that all the engines compared could be modified to produce the same power at the same altitude without appreciable changes in weight. In the case of the XP-42, the P-36A, and the P-40C, the engine of each of these airplanes has been rated at 1050 horsepower at some altitude, so it may be assumed that the radial engines could be supercharged to 1050 horsepower at 15,000 feet, or in other words, to the same power and altitude as that of the P-40C. The comparison would then show:

Airplane	Observed maximum speed (mph)	Maximum speed, at 1050 hp and 15,000 ft (mph)
P-40C	347	347
XP-42 long-nose	338	352
P-36A	315	335

The above comparison is subject to certain limitations. Primarily, the engine powers of the P-36A and P-40C were not measured by an engine torque meter and are

therefore open to some question. Some additional cooling power would be required to operate the P-36A and XP-42 engines at the rated power and altitude of the P-40C engine. Comparison of the aerodynamic effect of the engine installations is further complicated by the fact that other sources of drag are not strictly comparable because the gun installations on the XP-42 had been removed and, on the other hand, some detailed aerodynamic refinements such as the landing-gear fairing have been made on the P-40C.

The comparison, however, does seem to indicate that, by use of individual jet exhaust stacks and a long-nose high-inlet-velocity cowling, the installation of an air-cooled engine may be made to compare favorably with a conventional liquid-cooled-engine installation.

Pressures and temperatures.— The distributions of observed engine cooling-air pressures and cylinder temperatures for a typical high-speed level flight and for a full-power climb are shown in figure 14. For each case, the pressures are plotted in percentage of free-stream impact pressure, q_c . For the high-speed condition, the distribution of front and rear pressures around the engine is seen to be very nearly uniform; in fact, the pressures at the baffle entrances vary less with the location on the engine of the cylinders on which they are measured than they do with the point of measurement on the individual cylinder.

In the type of cowling under consideration, the engine cooling air is introduced to the front of the engine through a fairly narrow annular space, producing a jet in which the velocity is determined by the quantity of cooling air and the area of the annulus. The observed pressures on the front of the engine may then be expected to vary according to the location of the point of measurement with respect to the entering jet, the maximum amount of the variation being nearly equal to the velocity head in the jet. With a single exception probably attributable to experimental error, the pressures observed on the front of the engine fell between the maximum impact and the minimum static pressures measured in the annulus.

The average pressures on the front of the engine in the full-throttle high-speed condition were found to remain nearly constant at $0.83 q_c$ in the range of altitudes investigated. This value represents a loss of approxi-

mately $0.05 q_c$ from the average impact pressure of $0.88 q_c$ observed at the annular entrance to the engine compartment and an apparent loss of $0.12 q_c$ due to entrance and diffuser losses. The actual entrance losses are indeterminate because of the unknown amount of ram added by the propeller cuffs.

At first glance, the distribution of pressures on the front and rear of the engine shown in figure 14 for a full-power (full-rich) climb appears much more uneven than that for the high-speed condition. Except for two low points, however, the variation of front pressures was approximately 25 percent of the average pressure drop across the engine in both climb and level flight. In the climb condition, as in the high-speed condition, the variation with the point of measurement on the individual cylinder was greater than the variation with the location of the cylinder around the engine.

The rear pressures, on the other hand, were much more uneven in climb. Where the variation of rear pressures at high speed was only 5 percent of the average pressure drop, the variation of rear pressures in full-power climb was approximately 21 percent of the average pressure drop across the engine. The rear pressures were highest near the bottom of the engine, probably because of a combination of conditions due to angle of attack and the absence of cowl flaps at the bottom.

In the full-power climb condition, the propeller cuffs raised the average pressure at the entrance to the engine compartment to $0.98 q_c$ and the average pressure on the front of the engine to $0.86 q_c$ at the engine power listed in figure 14. The cowl flaps lowered the average rear pressure to $-0.26 q_c$, providing an average pressure drop across the engine of $1.12 q_c$, or 10.6 inches of water.

The distribution of cylinder-head and barrel temperatures is seen from figure 14 to be fairly uniform in the high-speed condition. The maximum deviation from the average temperature for both heads and barrels was less than 25°F . Little correlation is evident between individual cylinder temperatures and the pressure drops across those cylinders. The observed cylinder-head temperatures were relatively low and barrel temperatures were marginal in comparison with their specified limits of 500°F and 535°F , respectively.

Army specifications require that the installation be capable of operating within these limiting temperatures under "summer conditions," where sea-level air temperature is 100°F and the drop in temperature with pressure altitude is 3.6°F per thousand feet. For correcting tests to these air conditions, a 1:1 correction factor is specified for both heads and barrels. Figure 15 shows average and maximum observed head and barrel temperatures in relation to these Army summer limits, expressed here in $^{\circ}\text{F}$ above free-air temperature. It is observed that although the heads cooled satisfactorily, the average barrel temperatures were marginal and maximum barrel temperatures exceeded their specified limit in full-throttle level flight in the altitude range tested.

It is possible that a redistribution of the available cooling air effected by a change in the cylinder baffling would reduce the maximum barrel temperatures to their specified limit without increasing the cooling drag because the head temperatures were well below their limit.*

In order to evaluate the effect of small changes in air flow on cylinder temperatures, the pressure drop across the engine was varied at constant altitude and full power by opening the small cowl flaps used in the high-speed tests. The results are shown in figure 16. For an increase of 10 percent in volume of air flow, or an increase of 4 inches of water in average pressure drop across the engine, average cylinder-head temperatures were reduced 15°F and average barrel temperatures 10°F .

The interpretation of the temperature record obtained during the full-power climb at 140 miles per hour is open to some question, since there was a partial failure of the reference voltage used to avoid errors due to temperature effects on the galvanometer. The record obtained from the reference voltage consisted of three or four jagged steps instead of the smooth horizontal line previously obtained.

*Subsequent tests, to be reported later, on the same engine and thermocouple installation in a short-nose cowl showed that a reduction of 15°F in the temperature of the base thermocouples could be obtained by removal of the baffle sealing strips between the barrels at the bottom of the cylinders. These sealing strips are a special feature of the particular baffle arrangement provided by the Pratt & Whitney Company for the engine used in this investigation and are not present in the standard baffle installation for 1830 engines.

In all previous flights, the deflection of the galvanometer when the reference voltage was applied never departed more than 0.01 inch from a value of 0.89 inch. Since the instrument temperature was essentially the same as in the previous flights and since there was sufficient evidence to show that there was nothing wrong with the galvanometer itself, it is improbable that the galvanometer calibration should have changed materially from the nearly constant value it held in the previous flights. In the calculation of temperatures, therefore, it was assumed that the deflection of the reference voltage would have been 0.89 inch if the ballast tube and the connections from the reference voltage had been in good condition.

The temperature distribution calculated on the foregoing basis for the full-power, full-rich, climb at 140 miles per hour and shown in figure 14 is seen to have about the same pattern as observed for the high-speed condition at the altitude shown. At higher altitudes, however, the pattern changed considerably, as may be seen in figure 17. Since there was no change in the pressure distribution, it is probable that the change was largely an effect of mixture distribution as the mixture richened with altitude.

A more complete picture of the conditions obtained in the climb test is shown in figures 18 and 19. Figure 18 presents a time history of a climb to 11,000 feet at 160 miles per hour indicated, with the engine operating at 2550 rpm and 40 inches of mercury manifold pressure and with the carburetor mixture control in automatic rich.

At the end of this climb, a level run was made at the same manifold pressure and engine speed as in the climb. The level run was followed by another climb similar to the first except that the engine speed was 2300 rpm.

Figure 19 is a time history of a climb to 22,000 feet pressure altitude at 140 miles per hour indicated, 2550 rpm, full rich, with the manifold pressure up to the maximum rating for 5-minute operation except for the take-off. The pressure and temperature distributions for climb shown in figures 14 and 17 were taken from this test.

While the pattern of pressure and temperature distribution was essentially the same for the climbs at 140 and 160 miles per hour at the same altitudes, there was some change in the level of observed front and rear pressures. The pressures at the baffle entrances averaged $0.83 q_c$ and the rear pressures averaged $-0.16 q_c$ in the climb at 160 miles per hour, compared with $0.86 q_c$ and $-0.26 q_c$, respectively,

in the climb at 140 miles per hour at comparable altitudes (11,000 ft). The actual cooling pressure drops are shown in figures 18 and 19.

Inspection of figure 19 shows that the pressure drop across the engine decreased during the 140-mile-per-hour climb and was still lower during a subsequent level flight run at the same airspeed at an intermediate altitude. This fact indicates that the decrease in pressure drop was due principally to the decreased ram from the cuffs and lowered slipstream effect on the cowl flaps as the power dropped off. The data obtained indicated that the drop in front pressures was approximately equal to the rise in rear pressures.

The cylinder temperature records of figures 18 and 19 show that the cylinder-head temperatures were well below their limit at all times but that maximum uncorrected barrel temperatures were within 10° F of their limit of 335° F. Application of the Army "summer correction" would put the maximum barrel temperatures for the 160-mile-per-hour climb at 15° F over the limit and for the 140-mile-per-hour climb 2° F under the limit. If the climb at 160 miles per hour had been extended to the engine critical altitude, somewhat higher temperatures could be expected. Engine temperatures began to decline at lower altitudes in the 140-mile-per-hour climb in full rich partly because of the increase in mixture strength with altitude and partly because the engine power decreased with altitude from a maximum at ground level under the operating conditions specified for a 5-minute climb.

Aside from the pressures and temperatures encountered in cooling the engine, interest also lies in the ability of this type of cowling arrangement to supply air to the induction system and to the oil cooler.

The results of the pressure measurements in the induction system for the high-speed condition are shown in figure 20. The ram at the survey rake in the carburetor scoop above the engine averaged approximately $0.77 q_c$, and the static pressure at the same point was approximately $0.55 q_c$ in high-speed level flight above critical altitude. As may be noted from the pressure at the total-head collector in the carburetor throat, the loss through the screen at the entrance to the carburetor was almost three-fourths of the velocity head in the scoop. Measurements of impact pressure above the screen indicated that the loss at the bend above the carburetor was negligible.

Some difficulty was experienced in measuring the temperature of the air entering the carburetor because of recurring breakages of the thermocouple. The temperatures shown by the more reliable measurements, however, indicated that the carburetor air was approximately 30° F hotter than the ambient free-air temperature. Since the temperature rise due to adiabatic compression would be approximately half this value, the remainder must be charged to absorption of engine heat through the walls of the ducts.

The average ram to the front of the oil cooler in high-speed level flight was found to be the same as that in the carburetor scoop, approximately $0.77 q_c$. In this condition, the impact pressure behind the oil cooler was approximately $0.56 q_c$. In both of the climbs reported, the impact pressure on the front of the oil cooler averaged $0.66 q_c$ and pressures behind the oil cooler averaged approximately $0.30 q_c$.

Another item of importance is that of ground cooling. The temperatures observed during the ground-cooling test are plotted in figure 21. This test was made before the cuffs and the venting of the accessory compartment were modified to the conditions used in the flight tests, but it is believed to be representative of the airplane in the final condition in all temperatures except those in the accessory compartment. The temperature of the left magneto, which is in the accessory compartment, reached a maximum of 129° F after the engine was cut off. Corrected to summer conditions, this temperature would be 30° F over the Army limit. Since all other temperatures were satisfactory and since the improved venting materially reduced accessory compartment temperatures, it is evident that satisfactory ground cooling can be obtained by the use of cuffs with this type of cowling.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va.

REFERENCES

1. Silverstein, Abe, and Guryansky, Eugene R.: Development of Cowling for Long-Nose Air-Cooled Engine in the NACA Full-Scale Wind Tunnel. NACA A.R.R.. Oct. 1941.
2. Pinkel, Benjamin, Turner, L. Richard, and Voss, Fred: Design of Nozzles for the Individual Cylinder Exhaust Jet Propulsion System. NACA A.C.R., April 1941.

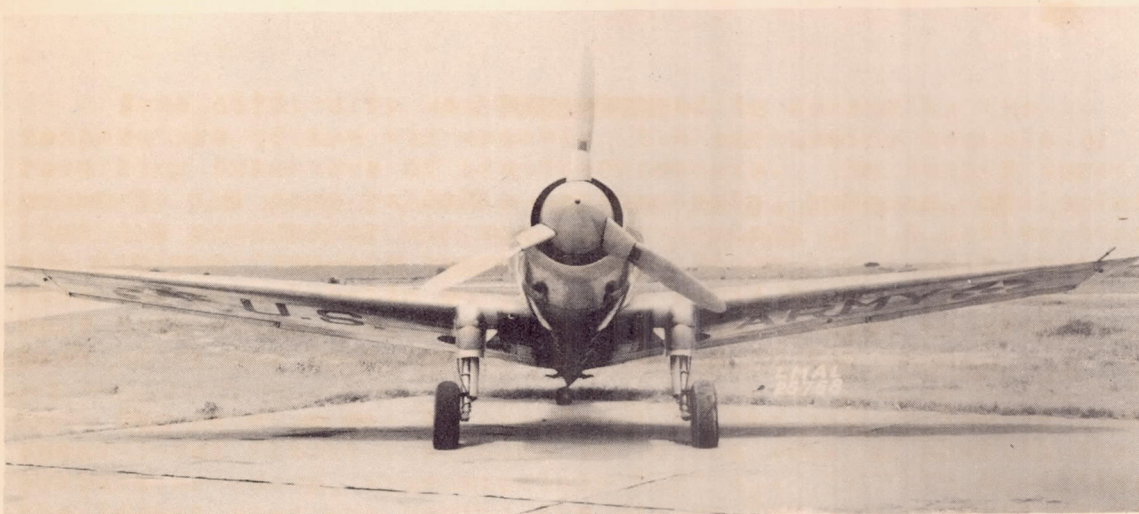


Figure 1.- Front view of XP-42 airplane with long-nose cowl

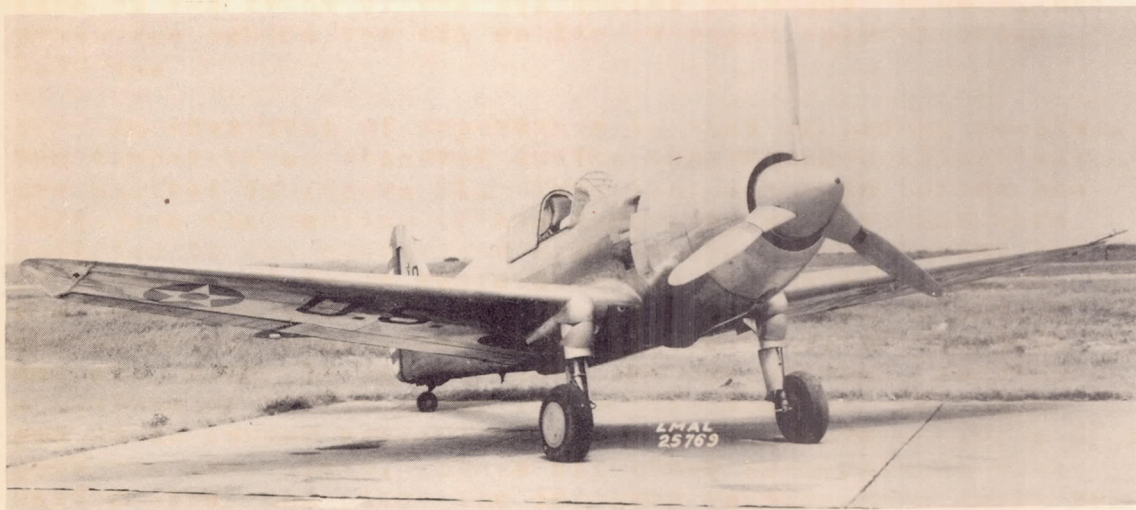


Figure 2.- Three-quarter front view.

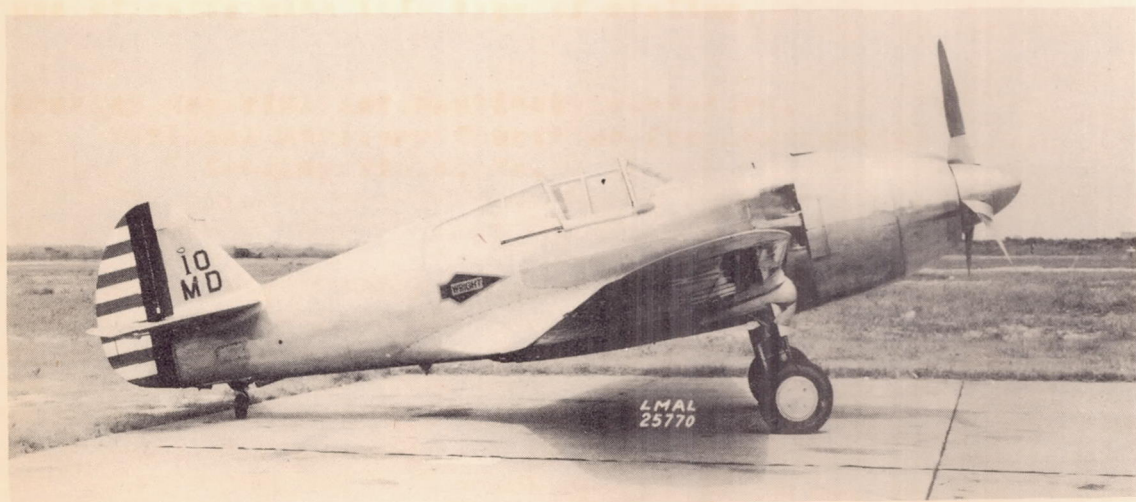


Figure 3.- Side view.

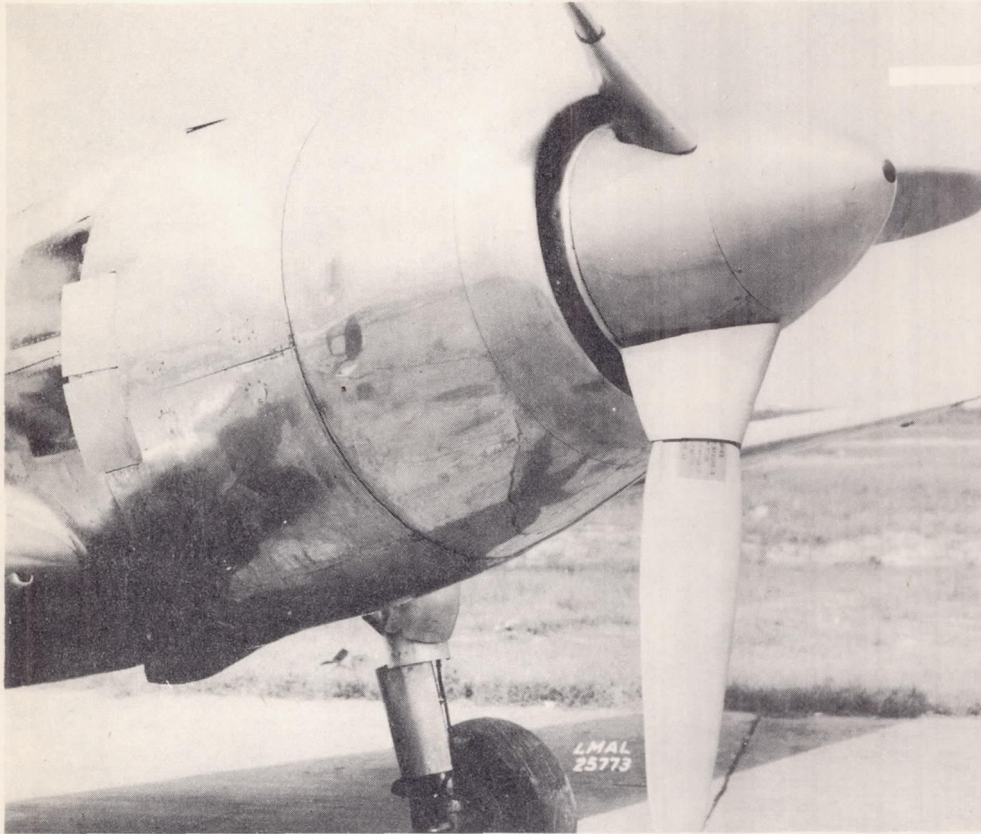


Figure 6.-

Close-up
of
long-nose
cowl
and
propeller
cuffs.



Figure 4.-

Single jet
exhaust
stacks for
cylinders
Nos. 1,14
and 13.

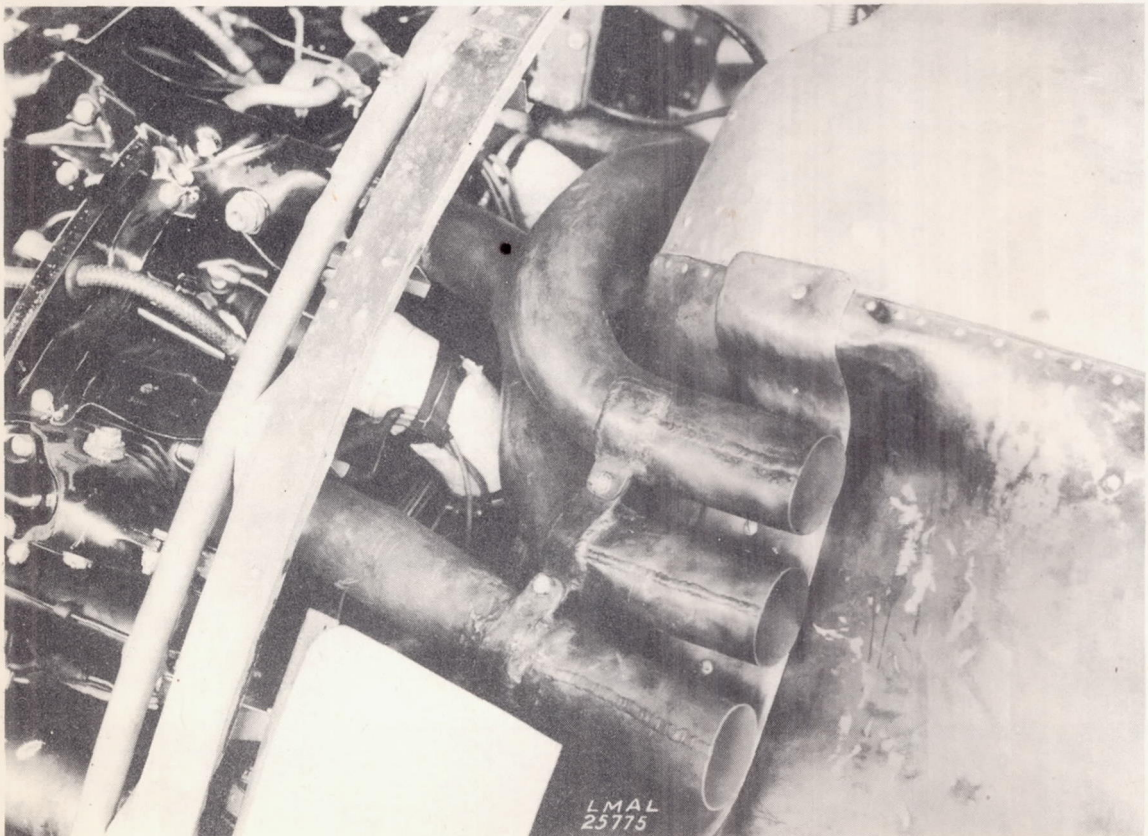
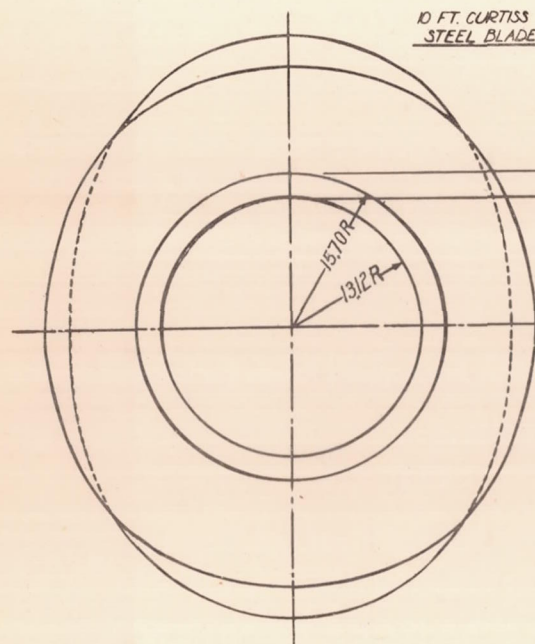
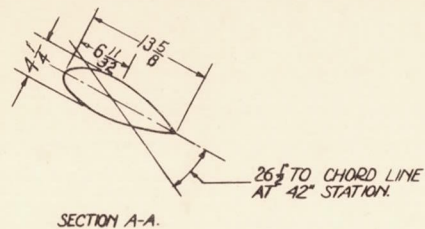
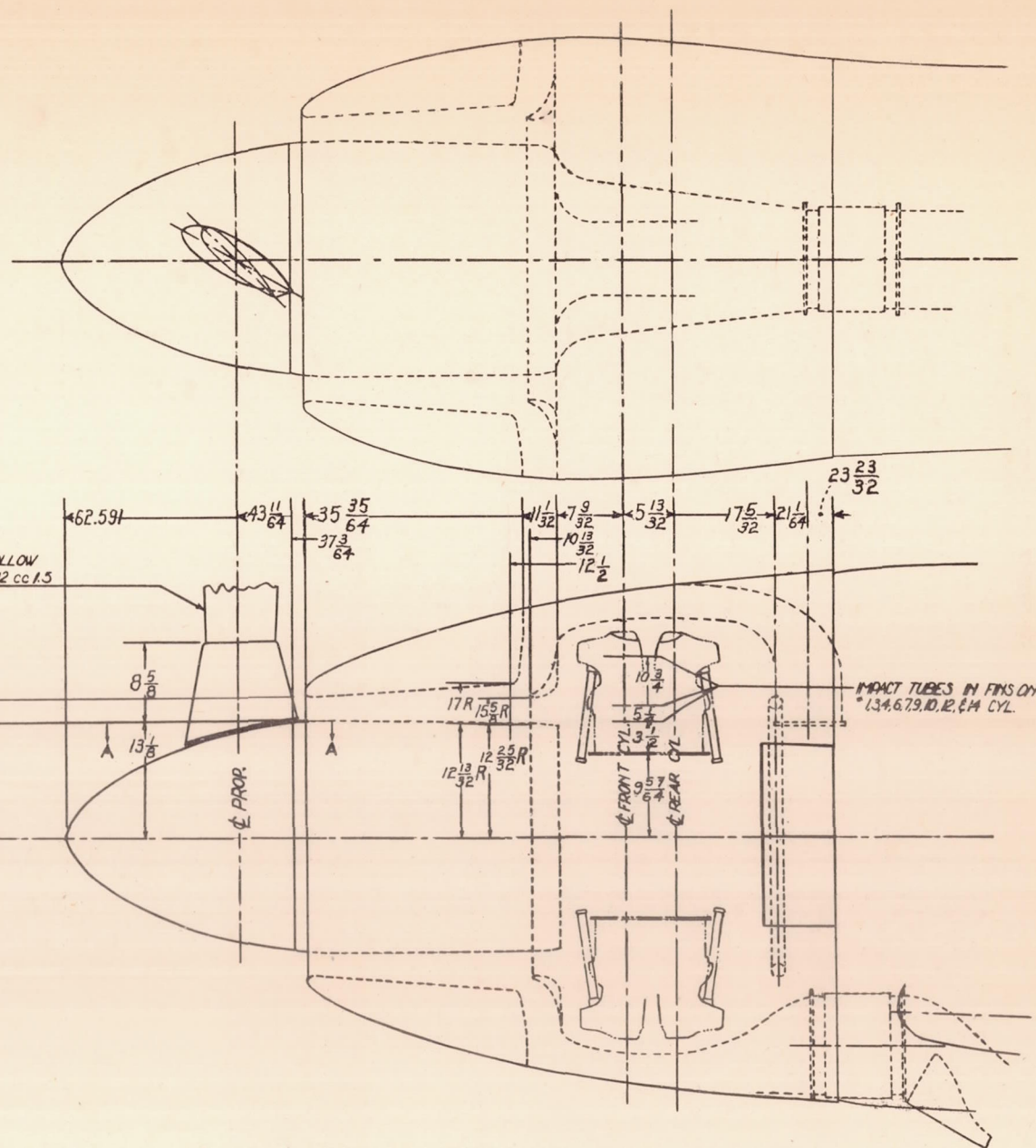


FIG. 5 XP-42 LONG NOSE HIGH
INLET SPEED COWLING.
(All dimensions in inches)



10 FT. CURTISS HOLLOW
STEEL BLADE 512 cc 1.3



MACA

Fig. 5

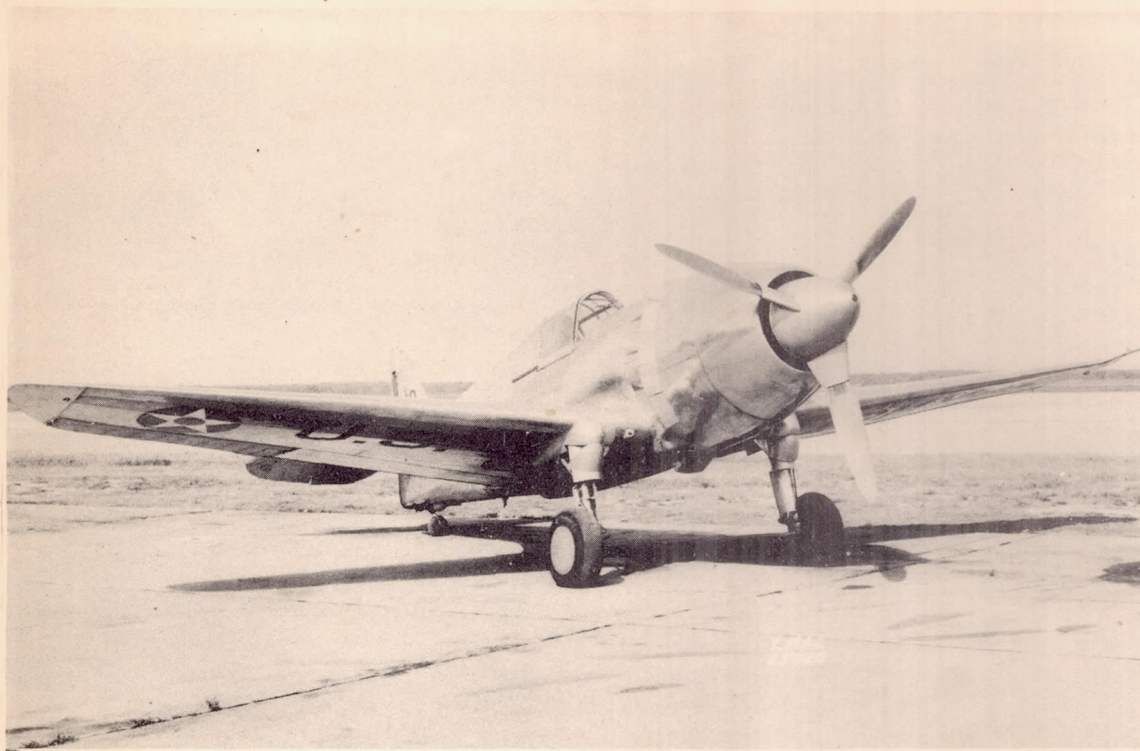


Figure 7.- Three-quarter front view showing modified cowl flaps.

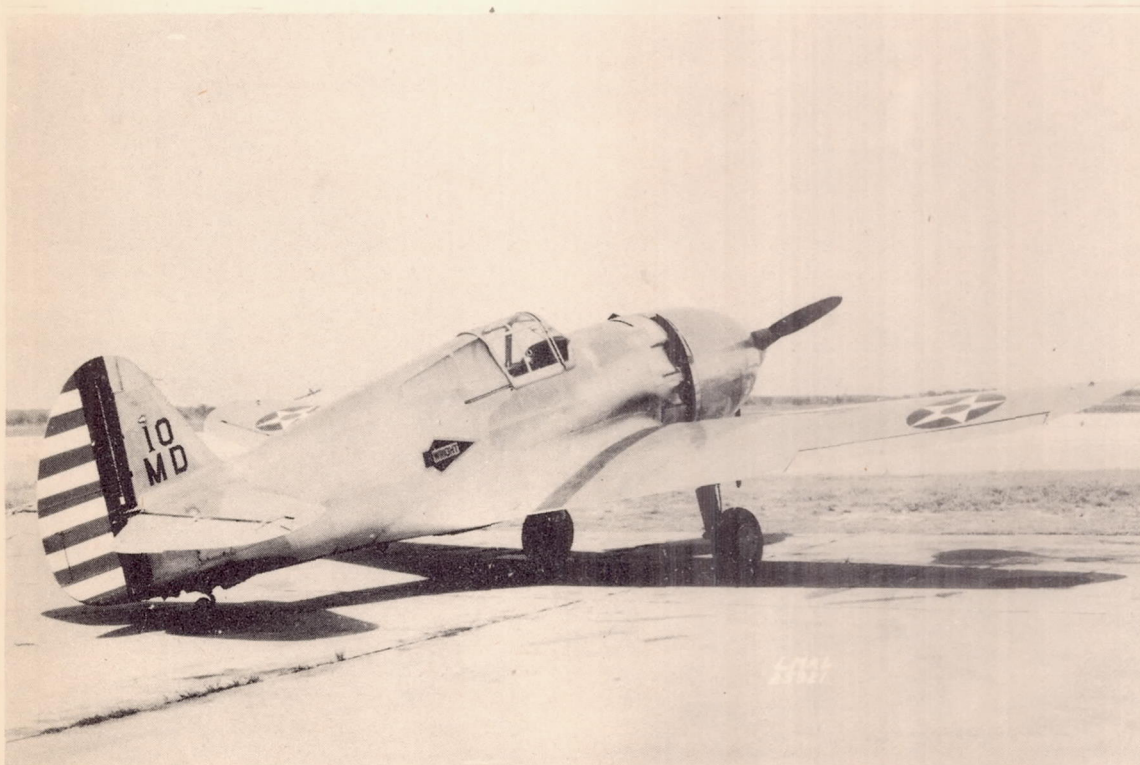


Figure 8.- Three-quarter rear view showing modified cowl flaps.

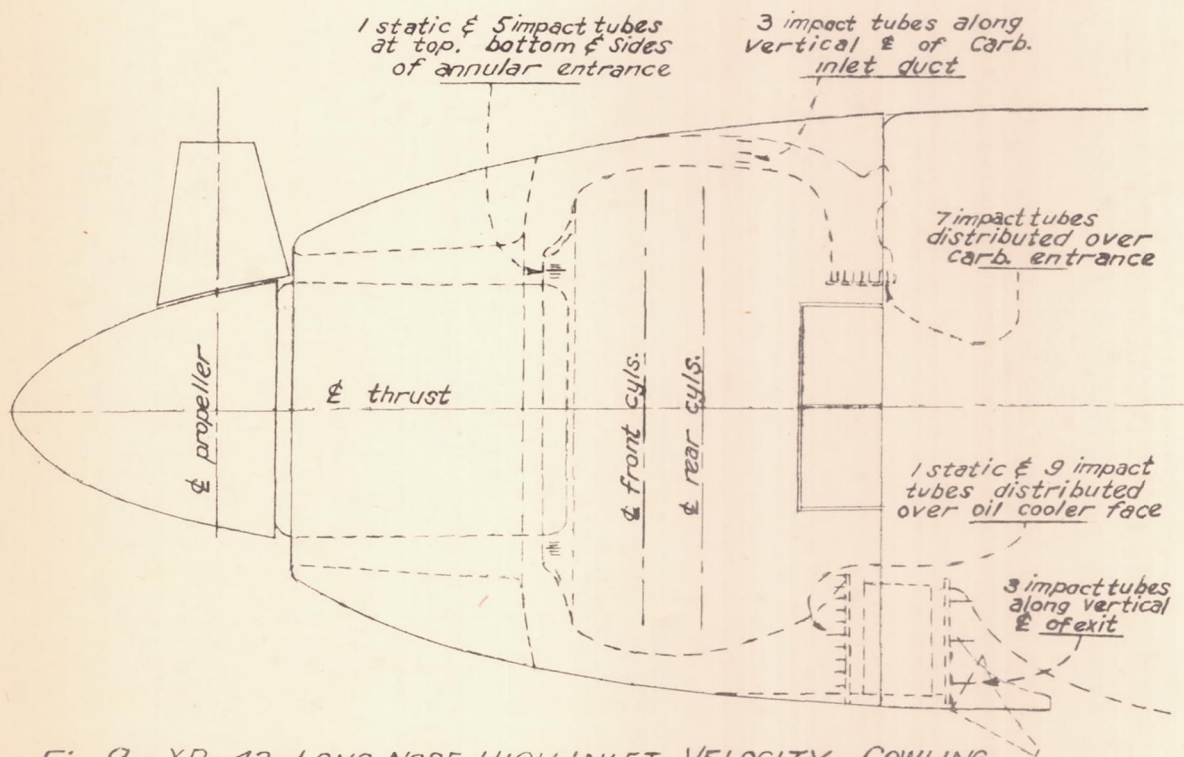
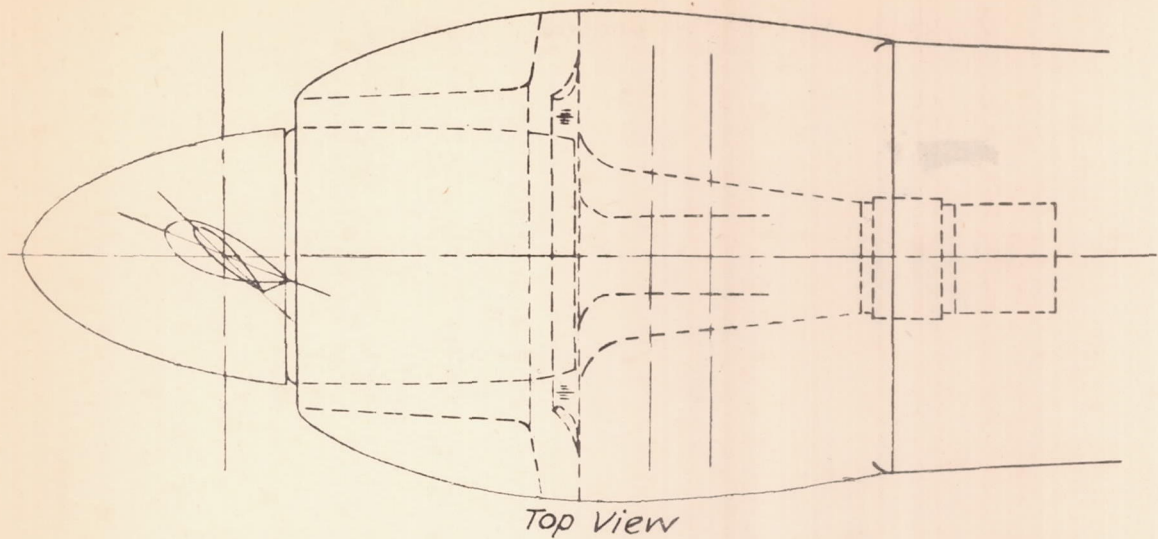


Fig. 9.- XP-42 LONG-NOSE HIGH-INLET-VELOCITY COWLING.

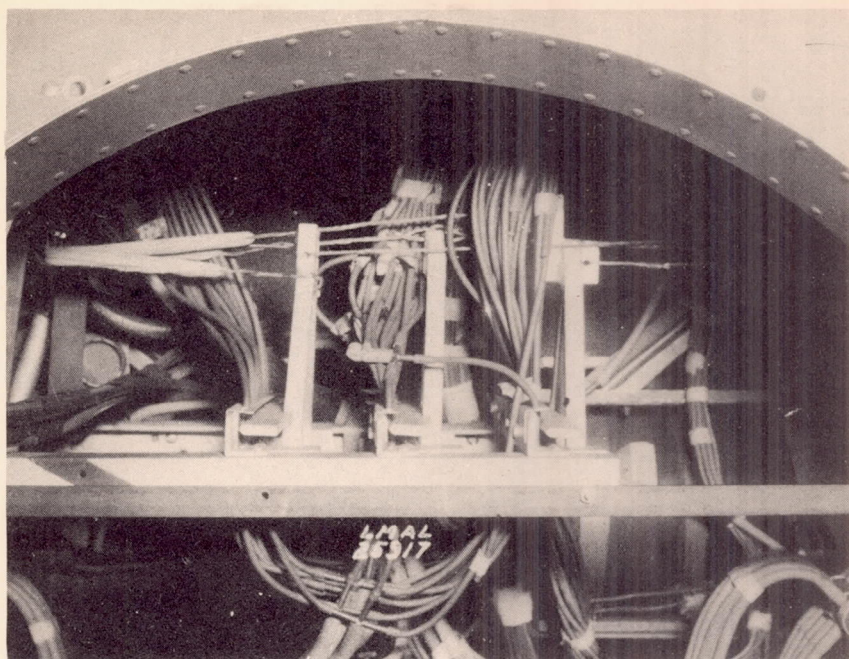


Figure 10.- Three-position pressure switch.

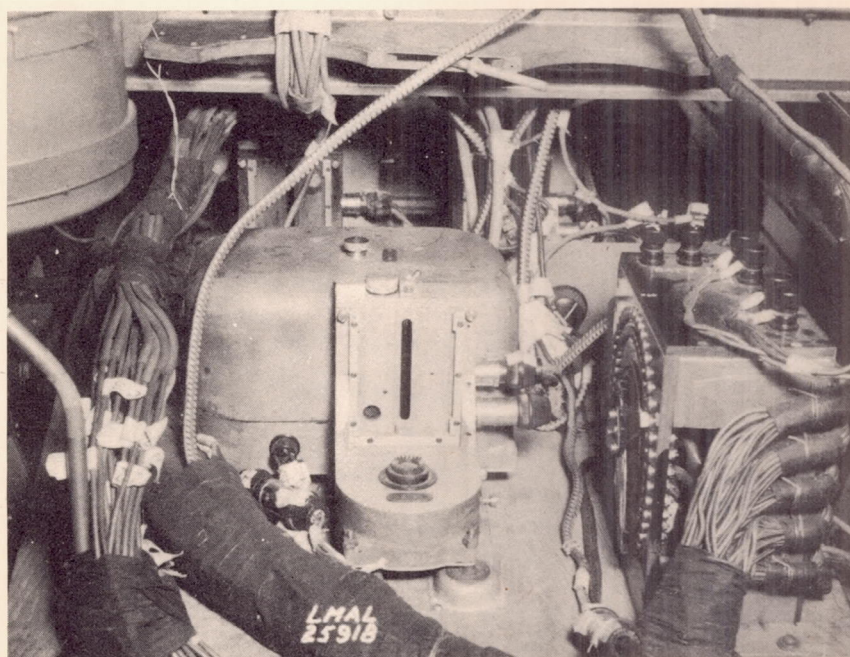


Figure 11.- Rotating thermocouple switch
and recording galvanometer.

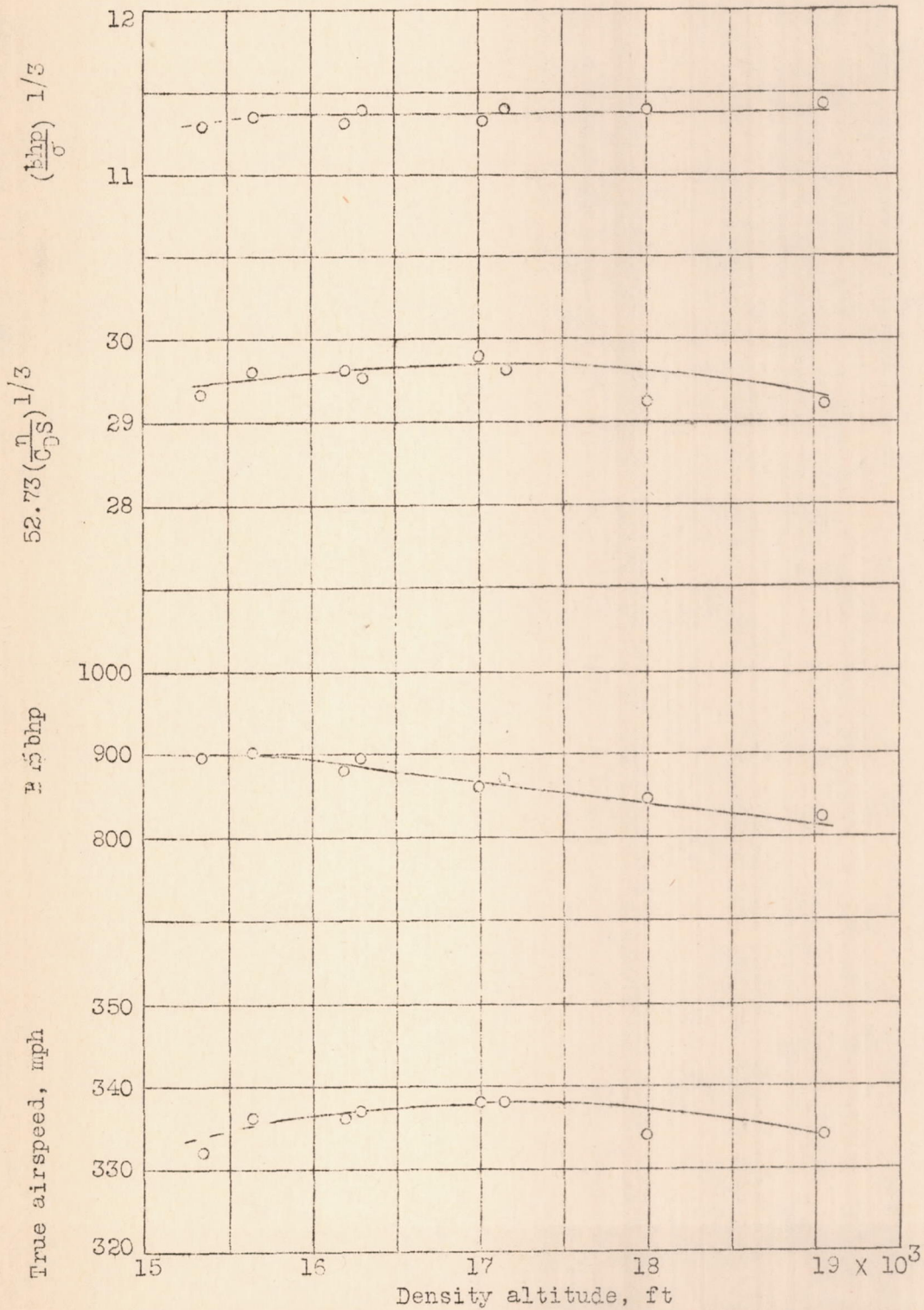


Figure 12.- High-speed performance of P-42 airplane with long-nose cowling.

NACA

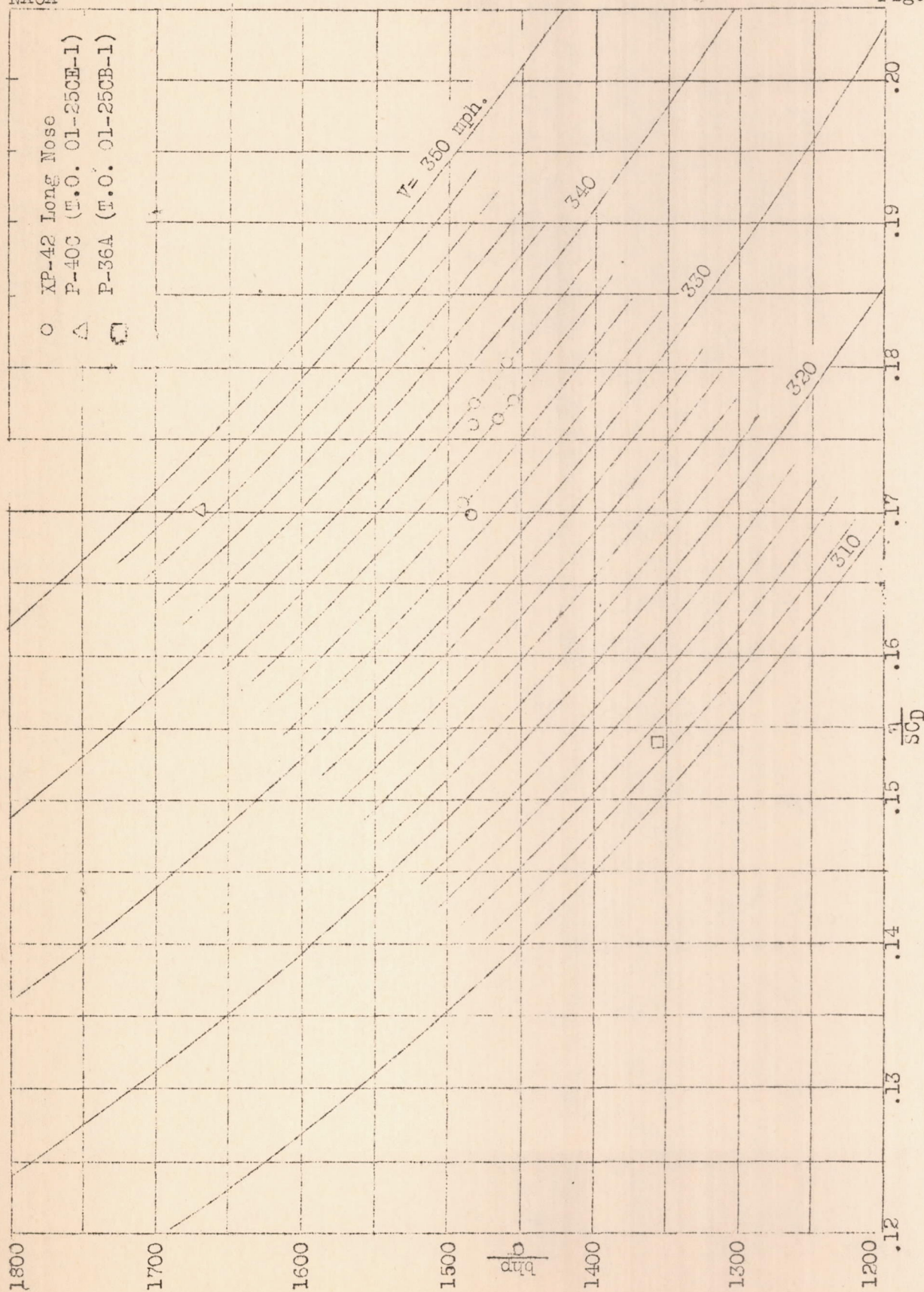


Fig. 13

Figure 13.- Comparison of high speed of several airplanes.

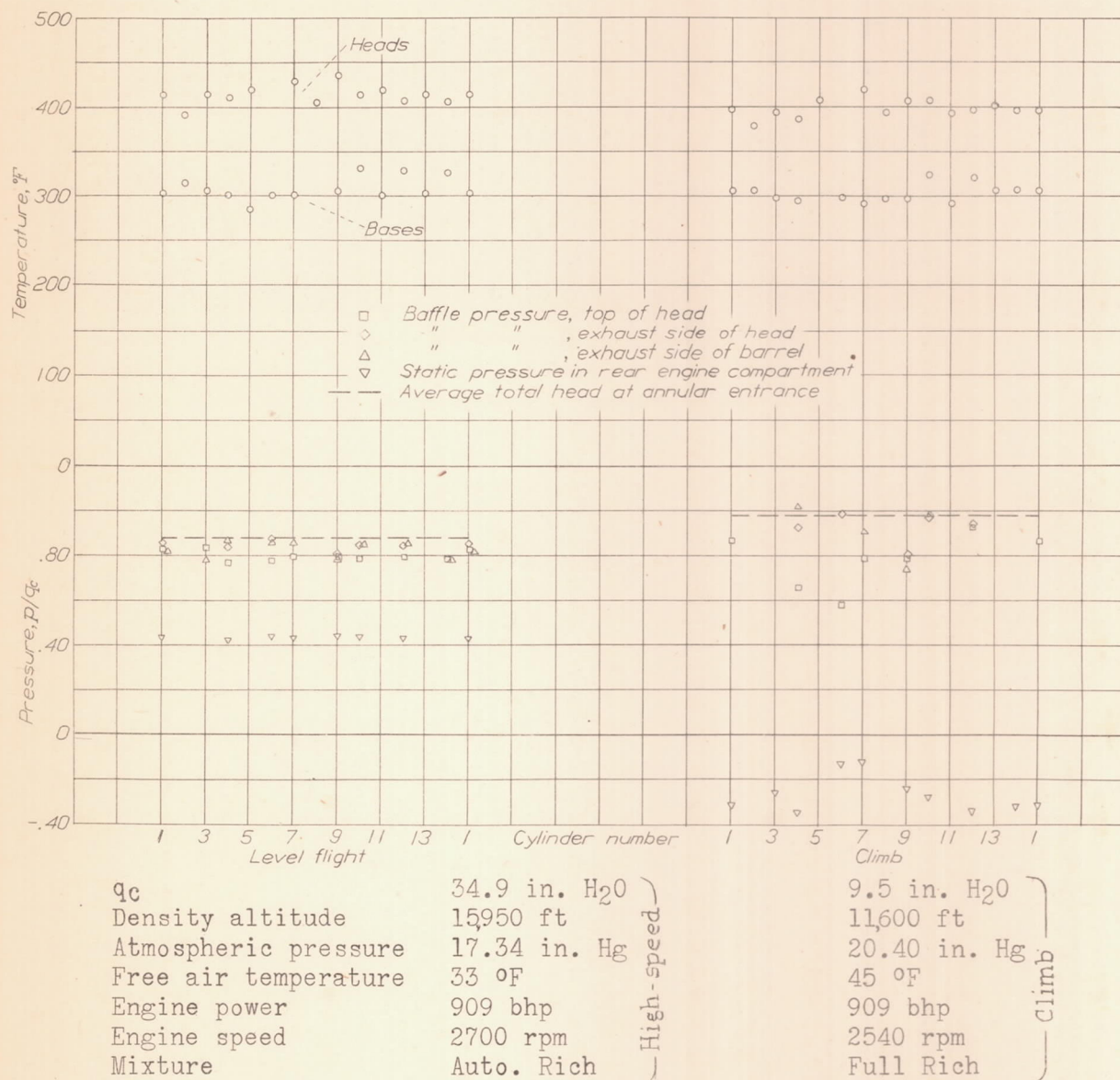


Figure 14.- Pressure and temperature distribution in high-speed and in climb.

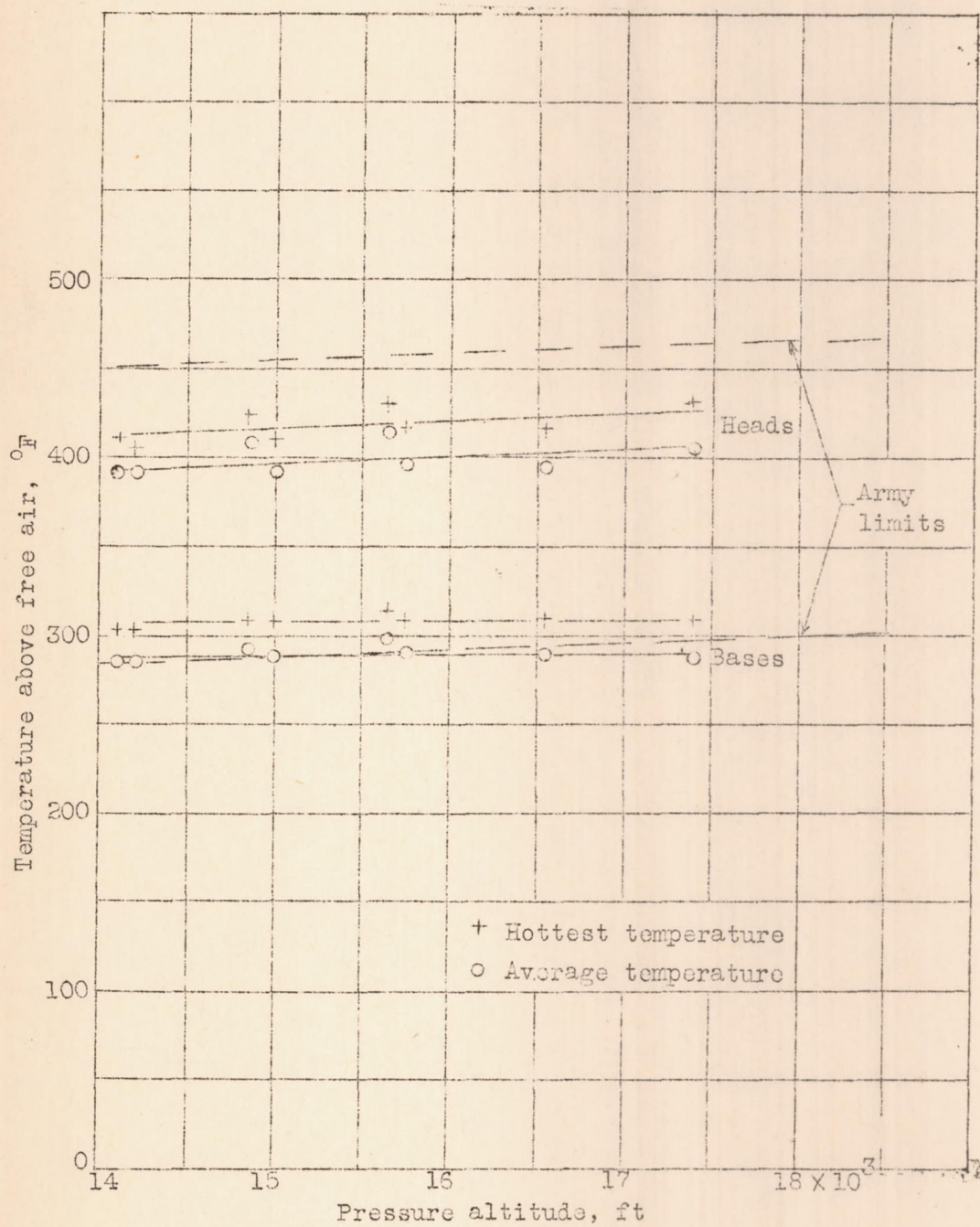


Figure 15.- Cylinder temperatures in the high speed condition in relation to Army limits.

L-356

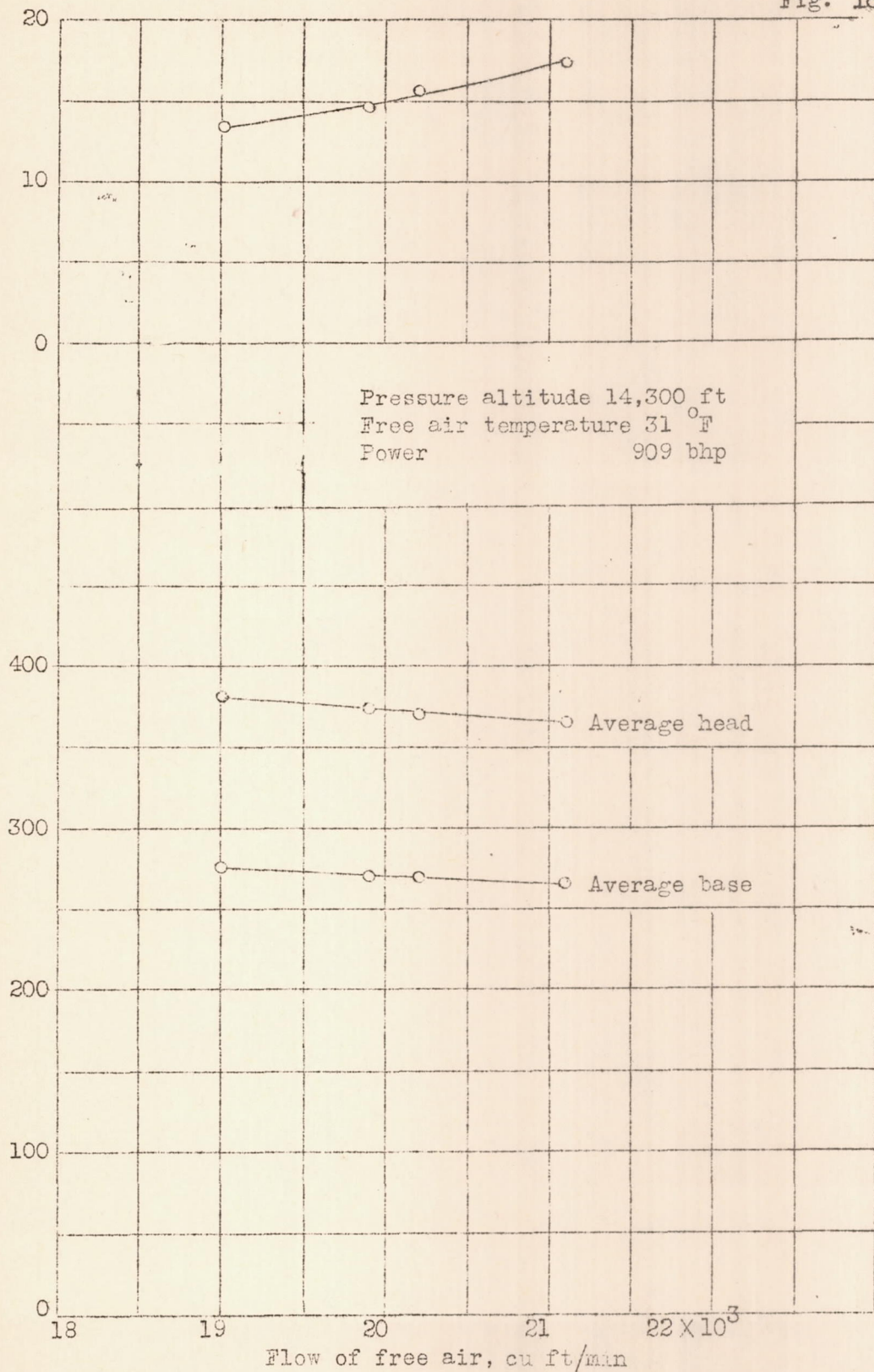
Pressure drop across
engine, in. H_2O Temperature above free air, $^{\circ}F$ 

Figure 16.- Effect of air flow on cylinder temperature.

L-356

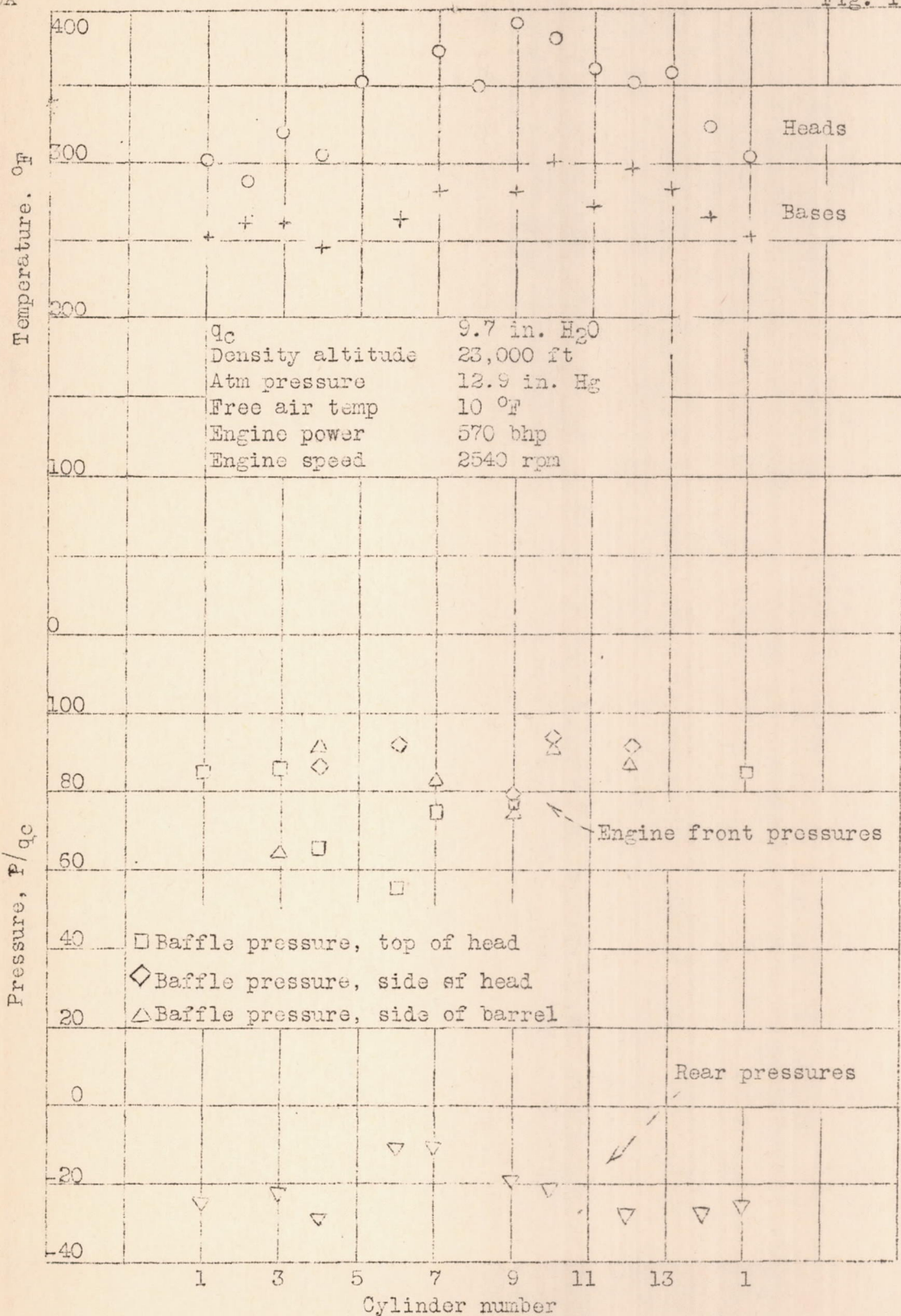


Figure 17.- Pressure and temperature distribution at 22,000 ft at end of climb.

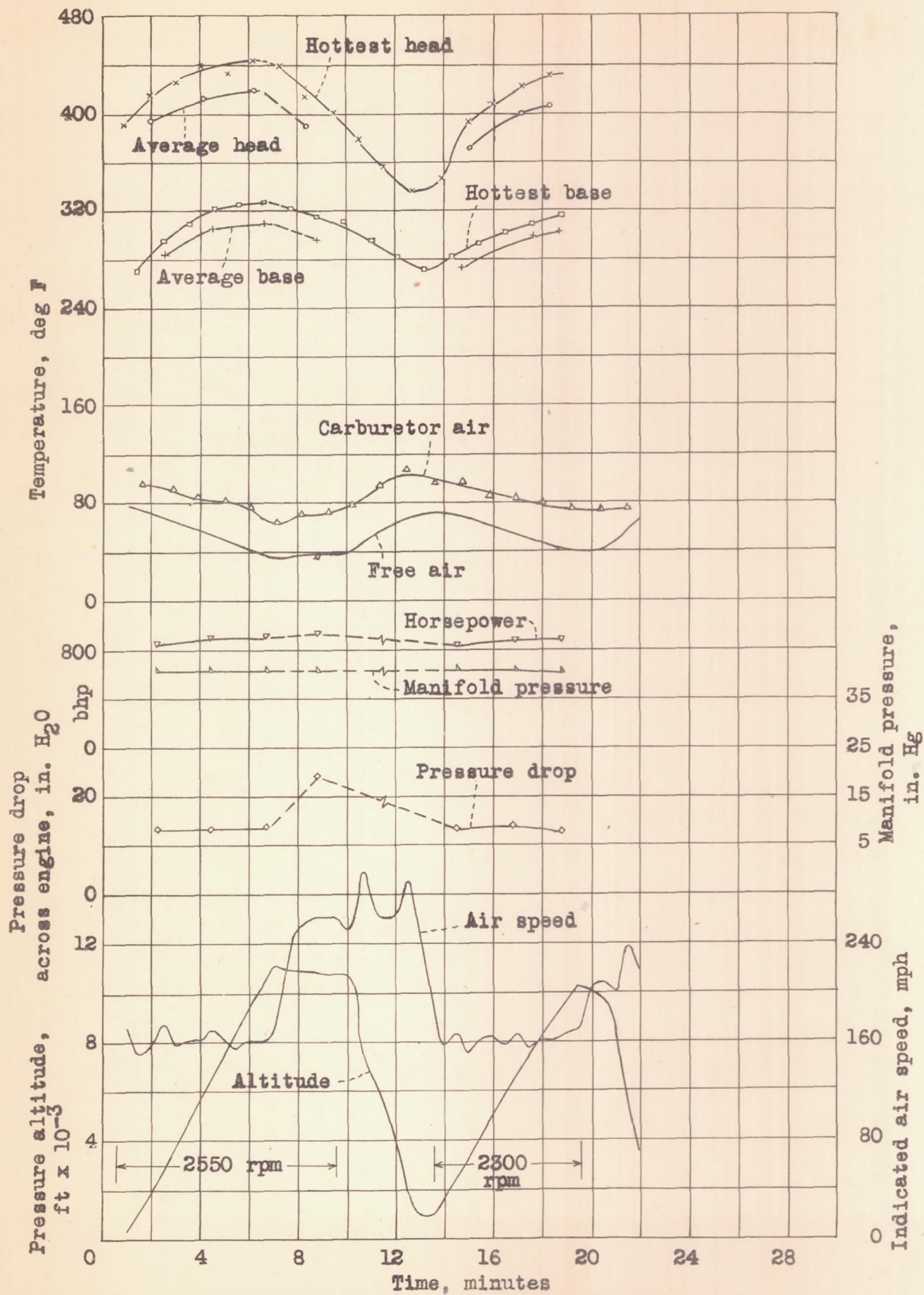


Figure 18.- Time history of climb at 160 mph indicated.

NACA 480

Fig. 19

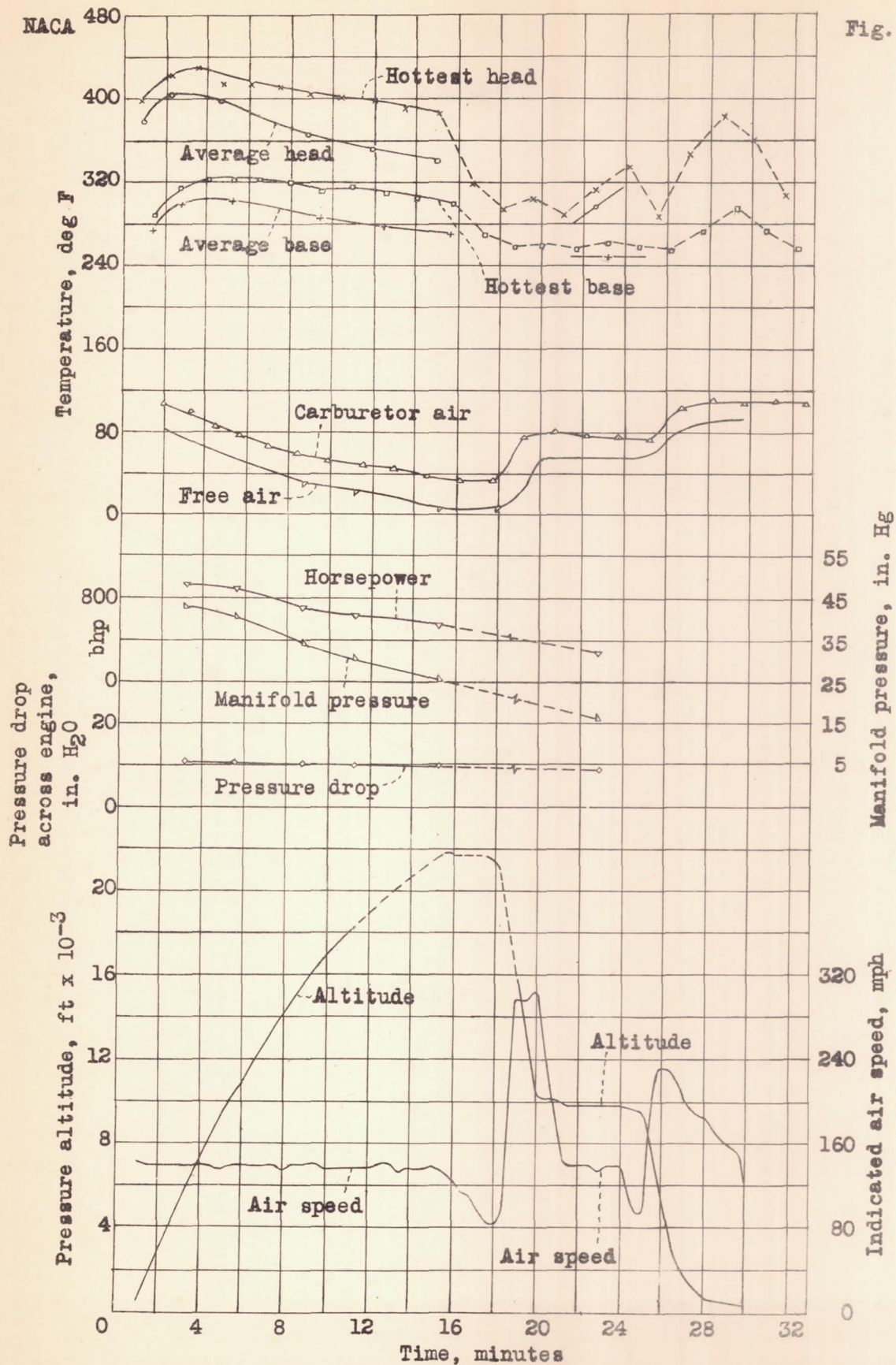


Figure 19.- Time history of a full power climb at 140 mph indicated.

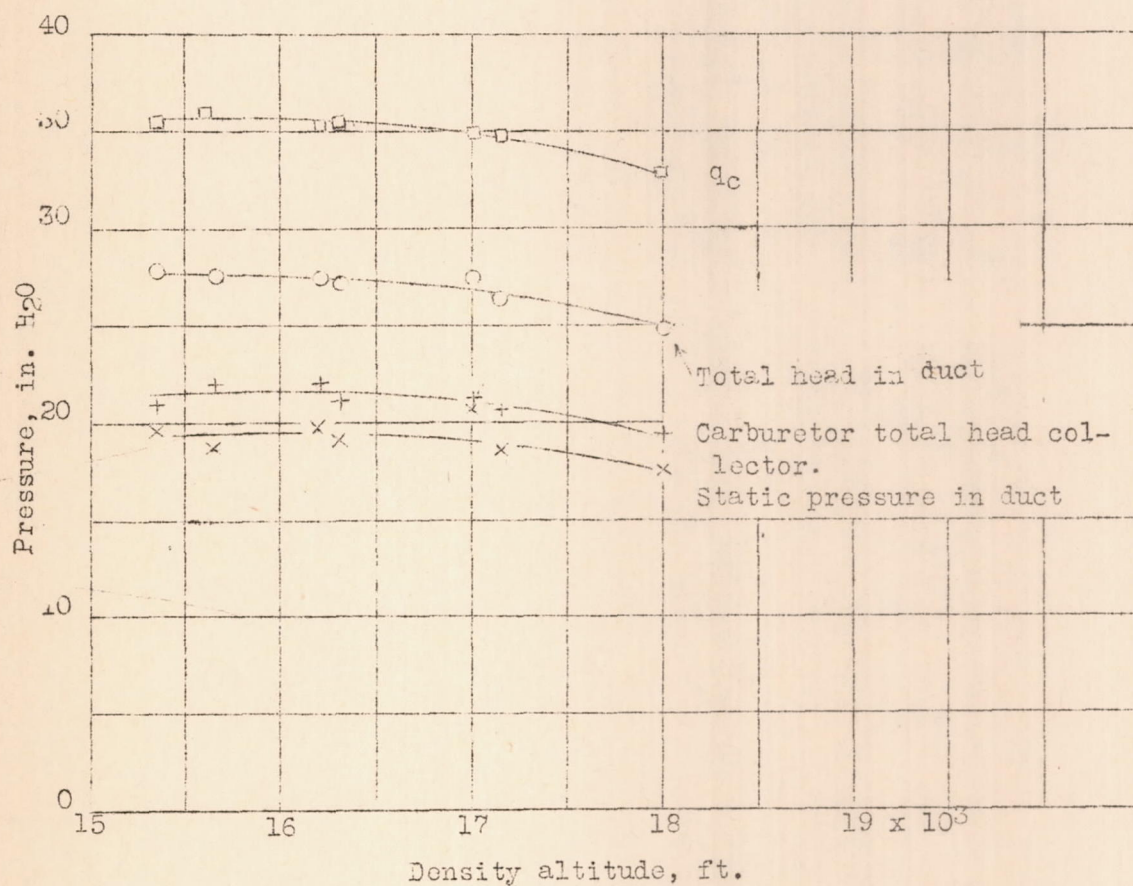


Figure 20.- Pressures in induction system in high-speed level flight.

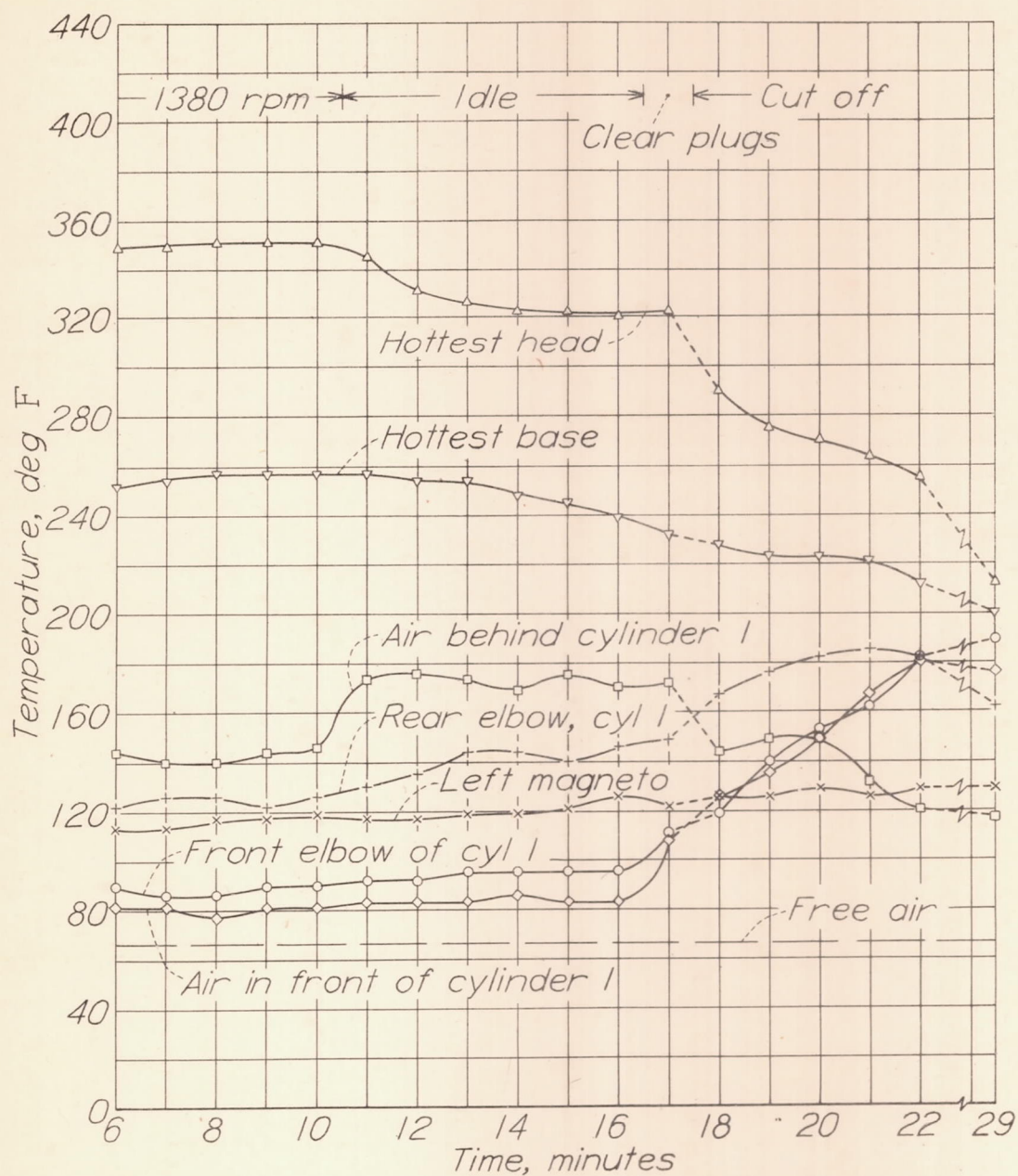


Figure 21.- Temperatures observed during ground cooling test with small cowl flaps open.